BELLCOMM, INC.
1100 Seventeenth Street, N.W. Washington, D.C. 20036

SUBJECT: Augmentation Requirements for Mission Control and Training Computers in the MCC-H - Case 103

DATE: February 23, 1968

FROM: J. R. Birkemeier
B. H. Liebowitz

ABSTRACT

[redacted]

This report presents the results of a study of augmentation requirements for the Real Time Computer Complex (RTCC) and the Simulation, Checkout and Training System (SCATS) in the Mission Control Center-Houston (MCC-H). Computer needs for several Apollo and AAP model schedules, representing a range of mission support demands, were investigated.

It was concluded that with certain changes in the present flight control philosophy a single 360/75 could provide flight control support for the most demanding mission foreseen--an AAP dual launch and rendezvous with an orbiting cluster. The changes include such things as delaying or suppressing selected telemetry data and updating telemetry displays less frequently than heretofore. Hence, the presently used stand-alone concept one computer with backup supporting all processing for a mission--can be used in the foreseeable future. It was also concluded that a single 360/75 could provide the Ground Systems Simulation Computer (GSSC) capability for any one mission if minor training compromises are made.

Further analysis based on maintaining the stand-alone approach led to the following conclusions:

1. The present RTCC-GSSC computer complement--six 360/75's and two 360/50's--is adequate for an Apollo-only schedule and for an Apollo schedule with three-month launches interleaved with a "light" AAP schedule.

2. The present complement of computers is inadequate for an Apollo schedule with two-month launches interleaved with a "light" AAP schedule. At least one more 360/75 would be required for program development.

3. If Apollo is interleaved with a "heavier" AAP, it would be desirable to put the additional 360/75 in the SCATS area so that simultaneous training exercises could be supported. It would also be desirable to convert the two 360/50's to a 360/75 with real time interfaces so that more simultaneous activities could be handled.

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pages 52
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Study areas which might lead to more efficient computer utilization were identified. These include: abandonment of the stand-alone approach in favor of functional processing; use of multiprogramming during program checkout; more efficient telemetry processing schemes.

Although the bulk of the analysis was performed prior to October 1967, much of the data is still relevant. Furthermore, areas are identified in which subsequent or continuing analyses were conducted. Since the analysis covered a broad range of manned space flight schedules, both the techniques and the results reported here should be useful for other studies such as the current Saturn V Launched Orbital Workshop Study.

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TABLE OF CONTENTS

Table of Contents (contd.)

Table of Contents (contd.)

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MEMORANDUM FOR FILE

1.0 INTRODUCTION

Current planning at NASA Headquarters indicates that Apollo and Apollo Applications Program (AAP) missions may overlap or interleave in time, and that some AAP missions may place heavy demands on existing ground support systems. The Bellcomm GOSS Augmentation Study conducted in July through September, 1967, investigated the impact of proposed manned missions on two major ground systems: the Mission Control Center-Houston (MCC-H) and the Manned Space Flight Network (MSFN).(1)

This report answers a question that formed a major part of the study: what augmentation, if any, is needed in the Real Time Computer Complex (RTCC) and the Simulation Checkout and Training System (SCATS) in the MCC-H?

The answer to this question depends on the type of schedule to be supported, a factor which had not been completely defined at the time of the study. Hence, the study team provided a range of answers to cover a set of baseline schedules (see Figure 1).* This memorandum documents both the answers and the methods employed to reach them.

2.0 BACKGROUND

The general flow of data on the ground in support of a mission is shown in Figure 2. The primary purpose of the computers within the RTCC is the direct support of a live mission. Operating in real time, these computers process telemetry and tracking data to update displays, determine trajectories, and carry out mission planning functions. They also handle commands sent by the flight controllers to the spacecraft. Before launch they are used extensively for testing the MCC-H and MSFN systems, for pad support, and for training flight controllers. The programs that support these functions are tailored for each mission.

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*The baseline schedules were formulated from NASA Headquarters plans as known during the study period and are combinations of "light" and "heavy" Apollo and AAP schedules. They provide a likely range of mission support demands.

The development and checkout of these programs is carried out on five IBM/75's located in the RTCC area of MSC's Building 30, two IBM 360/50's located in the IBM Building,* and one IBM 360/75 located in the SCATS area of MSC's Building 422.

The primary purpose of the computers within the SCATS is to simulate the trajectory and telemetry data flow from an actual mission to provide realistic inputs for training exercises within the MCC-H. There are presently three computers within SCATS: a Univac 418, a Univac 494, and the aforementioned IBM 360/75. The Univac computers are used for simulation control and remote site simulation respectively. MSC estimates indicated that these computers would be able to handle the expanded requirements dictated by Apollo and AAP schedules; hence they are not discussed further in this report. The 360/75, called the Ground Systems Simulation Computer (GSSC), which simulates space vehicles and MSFN ground systems, is considered in more detail, since there are circumstances which may dictate the need for its augmentation. GSSC programs are developed primarily on the 360/75 in Building 422 and the two 360/50's in the IBM Building, with some use of the 360/75's in Building 30 when they are available.

In addition to RTCC and GSSC program development and mission support, there are certain other tasks which require the use of the 360's. By far the largest of these tasks is the work involving the real time operating system (RTOS). This system undergoes continual maintenance, development, testing, and improvement for purposes of more efficient utilization of the computers. The simulation of RTCC and GSSC program execution to determine running times of program segments is another task requiring computer time. Smaller amounts of time are devoted to the gathering and processing of statistical data relevant to computer utilization, and administrative and configuration control record keeping for programs under development.

Computers outside of MCC-H, particularly the UNIVAC 1108's in MSC's computational facility, are also used for some related programming efforts, principally in the area of mission planning. Some of the programs developed in this manner are eventually incorporated into mission programs for RTCC. These activities, however, proceed independently of RTCC and were given no further consideration in this study.

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*There is no direct link between the 360/50's and the MCC-H, hence they are limited to off-line, job-shop type of program development.

3.0 ANALYSIS OF RTCC COMPUTER REQUIREMENTS

The number of RTCC computers required to support a particular schedule is dependent on: the real time support demands of individual missions as compared to the capability of a 360/75; the number of simultaneous missions; reliability goals; and the computer time needed for development, testing, training, and other prelaunch usage of the RTCC computer programs.

3.1 Capability of the 360/75

The RTCC operates in a "stand-alone" mode: a single computer processes all telemetry and tracking data for a mission in real time. With the advent of multiple launches and spacecraft clusters in the AAP, the amount of telemetry data is expected to increase greatly over Gemini and Apollo. It is natural then to question whether a single 360/75 will be capable of supporting an AAP mission, since a "no" answer to this question will greatly affect the number of computers required in the RTCC.

The analysis in this section will show that a single 360/75 can handle the worst case mission--an AAP-3/4 dual launch and rendezvous with the cluster--*if* certain flight control compromises are made.

3.1.1 Loading Factors

The RTCC processing load can be considered to be comprised of four major functions: real time telemetry processing; real time trajectory processing; event-dependent processing; and Real Time Operating System processing.(2) Real time processing, both for trajectory and telemetry parameters, must be completed within a specific time cycle to avoid loss of data. Event-dependent processing--e.g., maneuver planning, go-no-go processing, differential correction--is initiated either by flight controller request or the occurrence of some specific trajectory event. While not tied to a specific cycle, processing results must be available in a timely fashion, which could be from seconds to hours. Although no firm standards have been set, it has been estimated that between 39% and 50% of computing time during spacecraft contact should be reserved for such processing.(2)

3.1.2 Loading Data

The loading data used in this analysis are shown in Table 1. The time for RTOS overhead processing, which includes memory management and input-output functions, is included in the individual program processing times. The time for program swapping--bringing programs in and out of memory--being a function of total program size, is estimated separately. The telemetry processing estimates are given in terms of milliseconds of processing per telemetry update.* Dividing an estimate by the update period--currently one second--gives the fraction of time a computer's central processing unit (CPU) is processing a particular class of data. For example, Command and Service Module (CSM) telemetry processing takes 17.1% of the real time cycle (171 milliseconds/1000 milliseconds). If, however, telemetry data were updated every two seconds, CSM processing would take 8.55% of the real time cycle.

The telemetry loadings shown in Table 1 are based on IBM-Houston estimates for the AS-504 mission,(3) except for the Orbital Workshop-Multiple Docking Adapter-Airlock Module (OWS-MDA-AM) and the Apollo Telescope Mount (ATM) estimates, which were made by the authors.** The real time trajectory processing estimates are taken from a MITRE report.(4)

Analysis indicates that the computer program for AAP-3/4 will be comparable in size to the AS-504 program.*** Hence the swapping time estimates given in Table 1 are based on estimates for AS-504 as derived from conversations with MSC personnel.

3.1.3 Analysis of Worst Case Mission

It is estimated that the worst case processing load will occur somewhere during the launch of AAP-3/4 and its rendezvous with the OWS-MDA-AM. The exact loading is dependent on the mission plan, which is not yet completely defined. For the purpose of analysis the following assumptions were made:

a. The LM/ATM AAP-4 launch will occur prior to the CSM AAP-3 launch.

b. The manned CSM will be launched within a day of the LM/ATM.

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*Telemetry processing takes place each time updated telemetry parameters are transmitted from the Communication, Command and Telemetry System (CCATS) to the RTCC.

**It was assumed that the OWS cluster was equivalent to 1 1/2 unmanned CSM's and that the ATM was equivalent to one unmanned CSM.

***See Appendix.

c. During the launch, the LM/ATM will be covered by a shroud. It will be incapable of generating telemetry until the shroud's removal during the LM/ATM-CSM rendezvous.

d. The LM guidance computer will actively participate in the rendezvous of the CSM-LM/ATM with the OWS-MDA-AM.

Table 2 shows the processing requirements during the CSM launch, assuming that all possible telemetry sources are generating and that telemetry is updated at one-second intervals.

The result--∿97%--is intolerable since it is close to an overload situation, even without considering the requirements for event-dependent processing and program swapping. Unfortunately, the next phase of the mission--docking the LM/ATM with the CSM, followed by rendezvous with the OWS-MDA-AM--is worse yet. Here the real time telemetry and trajectory processing, exclusive of swapping and event-dependent processing, is ∿108% (see Table 3).

3.1.4 Methods to Reduce CPU Overload

In order to support the AAP mission in a single computer, major reductions in the processing load will be necessary. Such reductions can be effected by: reducing the number of parameters monitored; selectively turning off telemetry; delaying certain telemetry transmissions from the remote sites; reducing the telemetry update cycle. These methods can be used singly or in combination to relieve potential overload situations albeit at the expense of compromising flight controller operating procedures.

3.1.4.1 Reduce the Number of Telemetry Parameters

The processing time for telemetry is essentially directly proportional to the number of parameters monitored and the frequency with which they are updated. If the number of parameters is halved, the processing time will also be halved. It is doubted, however, that the present parameter estimates for AAP could be significantly reduced between now and the time the spacecraft configuration is frozen. In fact, the trend is usually towards increased parameters as time progresses. The best that can be said here is that the parameters must be controlled to keep the list as small as possible.

3.1.4.2 Reduce the Telemetry Update Cycle

Much more rewarding is the potential gain resulting from increasing the time between the telemetry updates. If, for example, the period for sending data from CCATS to the RTCC and the period for updating telemetry displays in the RTCC is increased to two seconds, the time for telemetry processing will be halved.* Hence, increasing the telemetry update period for the case shown in Table 3 would bring the combined processing time down to ∿62%**, exclusive of event-dependent processing and program swapping.

It should be mentioned that the Flight Control Division at MSC does not consider this approach to be desirable, since it decreases the probability of a flight controller detecting changes in telemetry parameters. Another penalty that must be paid is the cost of modifying the CCATS and RTCC telemetry processing program. However, this price is small compared to the overall development cost of the RTCC program.

To overcome the flight controller's objection, it might be desirable to selectively vary the telemetry cycle on a vehicle-by-vehicle basis. For example, if CSM data including the AMD and AGC*** are updated once each second, and the other vehicle data are updated once every two seconds, CPU utilization for the case depicted in Table 3 would be reduced to ∿77% exclusive of event-dependent processing, program swapping and additional RTOS time required for handling the more complex update rules. The selective approach would, however, require significant reprogramming and might actually increase CPU loading if not carefully programmed.

3.1.4.3 Selective "Turnoff" or Delay of Telemetry

Overload conditions can also be reduced by "turning off" certain emitters during worst-case situations.

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*This conclusion is based on an analysis of the CCATS-RTCC-Display computing cycle and has been verified in several conversations with MSC and IBM personnel.

**$(91.6)(1/2) + 14.5 + 2.1 = 62.4 \simeq 62\%$.

***AMD: Aeromedical Data
AGC: Apollo Guidance Computer

"Turn-off" can be accomplished by literally shutting off a telemetry transmitter or by not transmitting its data in real time from the remote sites.

One strategy might be to turn off the OWS-MDA-AM during the AAP-3/4 launch-rendezvous phase except for brief periods of checkout. That is, the data will only be monitored to determine if planned launches or maneuvers should be commenced. Once a commitment is made, the OWS-MDA-AM will not be monitored until it is time to make the next such decision. This strategy would provide 26% more processing time per cycle in the situations shown in Tables 2 and 3. In fact, a combination of a two-second cycle and suppression of OWS-MDA-AM data would reduce the CPU loading for the real time processing in the rendezvous phase to ∿49%. This strategy leaves more than 50% of the computing cycle available for program swapping and event-dependent processing.

The same improvement could be achieved by delaying the OWS-MDA-AM cluster data until CSM-LM/ATM contact is lost. In this case the cluster data would be processed during a lower level of activity, although it may still be competing for CPU time with the event-dependent processing. This delay could be accomplished either by sending cluster data post-pass from a remote site or by stripping these data out in CCATS, dumping them on tape and then playing the tape back to the RTCC during low activity periods.

3.1.4.4 Conclusions

Some change in the present method of flight control will be necessary to enable one computer to support the most complex AAP mission. The most promising approaches seem to be reducing the telemetry cycle and delaying or suppressing telemetry data. If these approaches are not used, then the number of computers required in the RTCC would increase greatly--perhaps by as much as a factor of two.

Considering all factors, economic and technical, it is concluded that it is both desirable and feasible to limit telemetry processing so that a single computer can process the data from the most complex missions. The analysis of computers required for a combined AAP-Apollo program, to follow, will be based on this premise.

This is not meant to imply that the stand-alone mode is necessarily the "best" way to process the data; there may be other configurations which could use the RTCC computers more effectively. However, such methods would necessitate extensive hardware and software development which would impact on the already tight schedules in effect in the RTCC. Because of this potential impact, these methods must be studied carefully in a longer range effort than that of the GOSS Augmentation Study. Our philosophy in this study has been to show how the stand-alone approach can be extended to AAP, thereby buying time to make such studies. Some methods deserving of further study are discussed in the concluding section of this report.

3.2 Computer Backup for Reliability

Although one computer can process all the data for a mission, subject to the constraints discussed in the previous section, backup computers may be required to obtain reliability objectives. The present philosophy is to use a "dynamic standby" computer (DSC) for critical phases such as launches and major burns. The DSC receives and processes the same inputs as the mission operational computer (MOC); its outputs, however, are suppressed. When a failure is detected, the DSC outputs can be switched to the control room within milliseconds, thus insuring continuous mission support. The original MOC is then taken off-line and repaired. Another RTCC computer, if available, is then activated to dynamic standby capability. In Gemini, this activation took 5-15 minutes; a new method currently being implemented will reduce this time to 11 seconds.

The problem of how many computers are required to provide adequate reliability is a complex one. In Gemini, it was concluded that five IBM 7094-II's were necessary to provide adequate support for one mission's critical phases. In a combined Apollo and AAP schedule, however, it may be necessary to support two simultaneous critical phases. A preliminary evaluation made by Bellcomm during the Augmentation Study indicated that with five IBM 360/75's and sufficient repair crews available, support for two critical phases would be available 99.993% of the time.* This analysis is based on a mean-time-to-computer-failure of 70 hours and a mean-time-to-computer-repair of two hours--as derived from current estimates and the use of a simplified reliability model.

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*This analysis has subsequently been verified and is documented in reference 5.

The analysis also indicated that at least four computers would be available 99.270% of the time and that all five computers would be available 86.86% of the time. These figures show respectively the availability of dynamic standby computers for both critical phases and the availability of a computer for other activities such as preventive maintenance and program development.

Hence, for the purposes of this study, it will be assumed that five 360/75's can provide support for two simultaneous critical phases with sufficient reserve for preventive maintenance and some program development.

3.3 Mission Program Development Requirements

The largest portion of computer time expended for a mission is devoted to program development. Two general categories of computer utilization can be distinguished: job shop and scheduled or block time. Job shop refers to programs that are processed more or less automatically in a batch mode under control of the operating system on a 360/50 or 360/75. About 20-25% of the total computer hours spent on program development fall into this category. During scheduled or block time, a programmer is allowed full and exclusive use of a 360/75 for a period of time. This category is intended primarily for testing programs in real time, when some communications with systems outside the computer are desired during the execution of the program.

The size and complexity of mission programs demand that programs for new missions be built as much as possible on those for previous missions of a similar or related nature. There are several factors, however, that contribute to the requirements for new program development for a given mission:

a. Differences in plans and objectives for various missions result in changes in computer operations to support the missions.

b. Spacecraft changes, although they may be relatively minor on successive missions, often produce changes in telemetry processing and therefore require revision of the affected programs.

c. Different crews and teams of flight controllers are involved on various missions, and certain individual preferences necessitate program changes.

d. Changes in mission programs can be expected as vehicles are flown and program deficiencies are revealed.

e. Limitations of time and resources force the adoption of priorities in handling program changes, and result in some changes being deferred to later missions.

f. The implementation of a specific computer function, even without changes in requirements, is subject to continual refinement and improvement to make better use of the computer's capability in real time and to provide a wider margin for contingencies.

A first-of-a-kind mission like the first Apollo lunar landing mission would necessarily involve extensive program development. IBM estimated that about 10,000 hours of computer time would be required for this mission. Subsequent Apollo flights, and AAP missions involving lunar landing, could then use this program as a base, and would require less computer time for development. Similarly, other AAP missions could build on the earth orbital rendezvous program developed for AS-258. After discussions with MSC and IBM, the following "learning curve" was developed by the authors:

a. Missions that involve a significantly novel hardware configuration (e.g., the orbital workshop of AAP-3/4) or operating environment (e.g., high-altitude earth orbit) would require 6000 hours of computer time for program development. The second mission of this type would require 3000 hours, and any subsequent missions would require 1500 hours.

b. Missions that were moderately similar in hardware and environment to previous ones would require 3000 hours of computer time for the first mission and 1500 hours for any subsequent ones.

c. Missions that were only slightly different from previous ones would require 1500 hours of computer time for each mission.

Computer time is not expended at a uniform rate in the course of developing a mission program. Early phases are characterized by short computer runs with extensive changes and corrections. Later runs involve more time as larger combinations of program segments are tested. For a typical mission, computer utilization increases gradually to a peak just before program delivery (normally three months prior to launch), then tapers off as final revisions and corrections are completed. Although, in actual practice, resource limitations and mission priorities may cause schedule adjustments to be made, some standard must be adopted for planning purposes.

Data provided by MSC and IBM was used to define non-uniform program development rates. Then, for each type of mission considered for Apollo and AAP, a judgment was made by the authors with regard to which of these rates was most appropriate. The rates and the assignment of missions to them are shown in Table 4. The mission designation used in Table 4 is based on Figure 1, with missions of the same type given sequential suffix numbers (A-1, A-2, etc.) where needed.

In viewing total RTCC requirements, it was found expedient to deal with numbers of computers rather than the amount of computer time needed to accomplish a task. The values in Table 4 were readily converted to numbers of computers by assuming that each computer could be available for 500 hours of useful operation each month. This figure allows an ample margin for preventive maintenance, unscheduled down time, rerunning of jobs as a result of computer failures or malfunctions, and accumulated lost time between jobs.

3.4 Other Computer Requirements

In addition to program development, requirements for computer utilization in any given time period can arise from other sources, as mentioned in the Background section of this report. Based on discussions with MSC and IBM, the following assignment of computers was assumed to meet these requirements:

a. One computer was assigned to full-time support of a flight in progress, for the maximum duration of the flight. (Flight duration was rounded up to the half month.) An additional computer was assigned to dynamic standby support during part of the mission; this requirement was expressed as a fractional computer assigned for the maximum duration of the flight. The fraction depended on the length and type of mission, and varied between 0.10 and 0.67.

b. Simulation and training occupied a 45-day period prior to launch and used a computer 0.75 of the time. This level, although somewhat higher than would generally be experienced for a single computer, includes an allowance for a dynamic standby computer during some phases of training and checkout.

c. Throughout the period covered by the baseline schedules, an average of 1.33 computers per month would be expended on operating system work, statistics gathering, and other overhead functions. This figure may at first appear to be high, but it must be remembered that there is a continual effort underway to improve the operating system so that the capability of a 360/75 can be realized more fully.

3.5 Results of Analysis

With the specific mission requirements detailed in the previous sections as a basis, the number of computers needed during each month covered by the five baseline schedules was determined. The results, expressed as the number of 360/75's required, are presented in Table 5.

It can be seen from Table 5 that the RTCC requirements reach peak values during the first year of each schedule. Several factors contribute to these peaks:

a. The unique program development time associated with the first Apollo lunar landing mission adds a heavy bias to RTCC activity, particularly toward the end of the first year.

b. Continuing program development for the J' mission of Figure 1 adds to the computer requirements during the early months of the first year.

c. Most other missions whose programs are under development during the first year are either first-of-a-kind or second-of-a-kind and therefore involve heavy computer requirements.

Although May of the first year is a local peak on all schedules, the early AAP missions cause higher peaks to occur later in the year for schedules II and IV. In actual practice, of course, attempts would be made to plan the program development for various missions so that peaks of this type could be reduced. Similarly, development of the operating system and other overhead activities would, as far as possible, be deferred to more convenient periods.

As a first approximation to the effect of planning program development to overcome peaks, the authors assumed a uniform development rate for each mission program. Specifically, a first-of-a-kind mission was assumed to require a full computer for 12 months; a moderately different mission, a full computer for six months; and a slightly different mission, half a computer for six months. The results are presented in Table 6. In every schedule, peak loads resulting from using these figures were lower than those presented in Table 5. Table 7 summarizes the results obtained from these two approaches to satisfying the demands for program development time. It can be seen from this table that by rearranging the program development tasks for various missions, local peaks can be reduced, and overall peak loads may occur at different times. While flexibility in planning may not always be possible to the extent desired, at least some capability in this regard can be expected.

As stated previously, the present complement of computers available for RTCC tasks consists of two models: 360/50's and 360/75's. In order to determine how well these computers can satisfy the requirements of the baseline schedules, it is necessary to make a judgment about the equivalence of these two models. For batch-type job-shop runs, a 360/75 may have as much as five times the processing speed of a 360/50. Many of the RTCC runs, however, involve large amounts of input-output activity; e.g., extensive printouts associated with core dumps. As a result, the speed advantages of the 360/75 cannot be fully exploited. As a simplifying assumption, the two 360/50's now available can be considered equivalent to one 360/75. This equivalence can be stated alternatively: if the two 360/50's were no longer available, an additional 360/75 would be necessary to retain the present capability.

In light of this assumption, the data given in Tables 5, 6, and 7 can be employed to assess the capability of the present complement of computers to satisfy the requirements of the baseline schedules. All schedules demand more than five computers for appreciable percentages of the time; therefore the five 360/75's located in the RTCC could not, by themselves support these schedules. The two 360/50's are used largely, but not exclusively, for RTCC tasks. If these computers could be used when needed, the equivalent of six 360/75's would be available. With reference to the data given in Table 5, it is reasonable to assume that the program development work required during the first year of schedule I could be rearranged to flatten the peak load in April and May, so that six 360/75's would be sufficient. The local peaks of schedules III and V could also be flattened in this manner; these peaks, however, are broad enough, particularly in the second year, to make one more computer highly desirable, at least for schedule III. Schedules II and IV show the highest and broadest peak loads, and would require one computer above the present complement and moderate rearranging of program development tasks to provide sufficient capability to meet these demands.

It is of interest to note that schedules II and IV show several months of heavy requirements during the fourth year. Actually, the total requirements during this year may be appreciably greater than shown in this analysis because whatever projects are to follow Apollo and AAP would begin to demand computer time during this period. Estimation of such projects, however, was deemed to be beyond the scope of the present analysis, and no further consideration was given to this aspect of the problem.

4.0 ANALYSIS OF GSSC COMPUTER REQUIREMENTS

The number of GSSC's required to support a particular schedule is influenced by: the ability of a 360/75 to simulate a mission; the number of simultaneous training exercises imposed by the schedule; and the computer time required to develop, test, and use the GSSC programs.

4.1 Capability of the 360/75

The total GSSC program consists of mathematical models, which simulate ground systems and space vehicles, and control programs. Each model and program utilizes a certain percentage of available CPU time. If, within an interval of time, the total time used by the programs exceeds the time available, simulation outputs will get delayed or suppressed thus affecting the reality of the training exercise in progress. Throughout Gemini a single IBM 7094 was able to perform the GSSC function. Training for the early Apollo missions, prior to replacement of the 7094's by 360/75's, required support from two GSSC computers primarily because of the increased complexity of the mathematical models involved. Introduction of the 360/75 enabled NASA to perform the GSSC function for Apollo missions with a single computer.

A question arises as to the viability of single-computer support in the face of forthcoming AAP missions. The answer to this question can be determined from an analysis of GSSC CPU loading estimates as shown in Table 8. The estimates for those programs marked with an asterisk are based on actual measurements made by IBM on Apollo programs under development. The estimates for programs with double asterisks are the authors', and are based on comparisons between Apollo space modules and AAP modules.

Basically the analysis for any one mission consists of determining which programs are used for the mission and then summing their CPU utilization times. In doing so, however, two factors must be considered: the CPU time required for program swapping; and a reduction factor to account for the fact that not all of the programs are utilized during an interval of time. Actual measurements on Apollo GSSC programs show that the combined result of the two factors reduces the actual CPU utilization to 85% of the sum of the individual program CPU utilizations. For example, if the CPU utilizations for those programs used in a Saturn I-B CSM launch simulation are summed, the result is 101% (see Table 9). However, actual GPSS* measurements indicate a peak loading of 85%, approximately a 15% reduction. This reduction factor will be used in the AAP analysis although there is no guarantee that it will remain constant for all GSSC programs.

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*GPSS - General Purpose Systems Simulator: a computer program used by IBM to predict running times for RTCC and GSSC programs.

It is now possible to consider some worst case situations, all of which arise during the AAP cluster mission.

Case 1: AAP-3 Launch

The programs used for an AAP-3 launch are shown in Table 10. In this case a manned CSM is launched to rendezvous with the orbiting LM/ATM; the OWS-MDA-AM is in another orbit. The total CPU utilization, as determined by straight addition, is 131%; after applying the 15% reduction factor, the loading is ∿111%, which indicates a computer overload.

However, a slight compromise in training policy can alleviate this situation. The insertion ship model accounts for 30% out of the 131% CPU loading. This model is used to provide training for the flight controller aboard the insertion ship. It is not, however, imperative to train him during a launch which leads to a rendezvous since he is not involved in controlling the rendezvous. He could, for example, be trained during the AAP-4 launch exercise which is less demanding of GSSC time. This strategy would permit removal of the ship model from the AAP-3 simulation and bring the CPU utilization down to ∿86%*, a high but acceptable figure. In addition, there may be one other mitigating factor. If, as suggested in the earlier discussion of the RTCC, the OWS-MDA-AM is shut off during the launch of AAP-3, then the figure is further reduced to ∿77%**.

Case 2: AAP-3/4 Rendezvous With AAP-1/2

The programs used in this case are shown in Table 11. The insertion ship model is not included since the ship performs no function during this part of the mission. The Saturn IB models are not included, since the launch vehicles play no role in the rendezvous.

The sum of individual CPU utilizations is 95%; applying the reduction factor it becomes ∿81%, which is an acceptable figure.

Judging from these cases it is concluded that a single 360/75 can support the most complex AAP training exercise, if the insertion ship model is removed from the AAP-3 launch simulation.

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*(131-30) x .85 $\simeq$ 86%.

**(131-30-10) x .85 $\simeq$ 77%.

4.2 GSSC Reliability

Reliability considerations are not as pressing for the GSSC as they are for the RTCC computers. If a GSSC fails, schedules may slip--but in general there will be no danger to human life. Hence the concept of a dynamic standby has never been, and is not planned to be, used in the GSSC. However for heavy support levels it would be extremely useful to have two computers that can perform the GSSC function. If one fails the other can be brought on line to avoid undue delay in training exercises and program development. (This was possible in Gemini, since all five 7094's were in one room and could be used interchangeably as GSSC or RTCC computers.) Also two GSSC's would facilitate support of simultaneous training activities if required by a particular schedule.

The present setup precludes this. A backup capability can only be achieved if another 360/75 is brought into building 422 or if the GSSC function is brought back to building 30.

4.3 GSSC Program Development

The development of programs for the GSSC follows much the same course as that for the RTCC, and many of the points presented for the RTCC apply to the GSSC as well. Based on discussions with MSC personnel, the following assumptions were made to assess the computer requirements for GSSC program development:

a. Program development starts eight months before launch.

b. The first three months of program development involve mostly job-shop work on 360/50's. The 360/75's could also be used if time is available on them. For first-of-a-kind missions (viz., A-1, C-1, F-1, H, and I in Figure 1), the computer time required is equivalent to 25, 50, and 75 hours per month on a 360/75. Other missions require half these values for each month.

c. The next two months require the use of the 360/75 in Building 422. For first-of-a-kind missions, the utilization rate is 275 and 225 hours per month during this period. Other missions require half these values for each month.

These requirements were converted from hours per month to the number of computers by assuming, as with the RTCC, that each computer would be available 500 hours per month.

4.4 Other Computer Requirements

The GSSC is utilized extensively before launch for system test and validation, and for training. MSC experience shows that a 360/75 is needed about halftime during the three-month period just prior to launch, and this utilization rate was assumed in the analysis. Since the GSSC uses the same RTOS as the RTCC, no additional computer time need be allocated for development on the RTOS.

4.5 Results of Analysis

The GSSC requirements for each baseline schedule were determined on a month-by-month basis. The results are presented in Table 12 as the total number of equivalent 360/75's required for GSSC tasks.

As with the RTCC requirements, some planning of program development activities may be expected to reduce local peaks in the schedule, if necessary. As a first approximation of the effect of such planning, a "uniform" development rate was assumed by the authors, as follows:

a. The first three months of program development for a first-of-a-kind mission use computer time equivalent to 50 hours per month on a 360/75. Other missions use 25 hours per month.

b. The next two months require 250 hours per month of 360/75 time for a first-of-a-kind mission, and 125 hours per month for other missions.

The results obtained by using these values are presented in Table 13 and summarized, along with the results of Table 12, in Table 14. By comparing corresponding figures in Tables 12 and 13, it can be seen that the requirements are not affected as much by the assumed development rates as they were in the case of the RTCC. This difference arises primarily from the fact that even the uniform rates assumed in the analysis actually consist of two rates, one for the first three months and the other for the next two months. Furthermore, the month-by-month variation in the development rate is not as great for the GSSC as for the RTCC, and does not extend over as long a period.

All schedules demand more than one computer for large percentages of the time; therefore, the one 360/75 now located in the SCATS area could not, by itself, support these schedules. Part-time usage of the 360/50's and, if available, the RTCC

360/75's could increase the GSSC capability to the equivalent of 1.5 360/75's and would satisfy the needs of schedules I and V, with minor rearrangement of tasks in the latter. The other schedules require a much greater increase in GSSC capability, either by more extensive usage of the 360/50's or the RTCC 360/75's, or by the installation of another 360/75 for GSSC applications.

5.0 COMBINED RTCC - GSSC COMPUTER REQUIREMENTS

As stated previously, the 360/75 used for the GSSC is physically removed from the 360/75's in the RTCC. This fact somewhat complicates the analysis because it prevents an unrestricted pooling of resources to meet the combined needs of the RTCC and the GSSC. On the other hand, both the RTCC and the GSSC make use of the 360/50's, and the GSSC is able to use job-shop time on the 360/75's when available. It is also possible that there will be a closer integration of the GSSC with the RTCC, particularly if any major expansion of facilities occurs, as would be required to support schedules II and IV. Pooling would then be easier to realize. For planning purposes, therefore, it is useful to combine the requirements of the GSSC with those of the RTCC. Table 15 represents such results for non-uniform development rates, and Table 16 for uniform development rates. Table 17 summarizes the results for both development rates.

Besides raising the general level of computer requirements, the addition of the GSSC tasks causes the peak loads for schedules III and V to be shifted to the second year, when flights of Apollo and AAP missions begin to mix. Schedules I and V could be handled by the present combined complement of computers (6 360/75's and 2 360/50's) with some rearranging of program development tasks around the local peaks. Somewhat more extensive rearranging would also bring schedule III within present capability. With one additional 360/75, most of the demands of schedule II and IV could be readily satisfied; however, considerable rearranging of program development tasks and extensive pooling of GSSC requirements within the RTCC would be necessary to meet the peak load conditions of these schedules.

6.0 SUMMARY AND CONCLUSIONS

The number of computers required for the RTCC and the GSSC was analyzed for various schedule densities. The analysis was based on the premises that a single 360/75 can provide real time support for the most complex mission envisioned and that a single 360/75 can provide the GSSC function for the mission.

These premises are valid if certain changes in present flight support philosophy are made. For the RTCC, telemetry processing will have to be reduced by a combination of decreasing the number of parameters to be processed in real time, increasing the time between telemetry updates, and suppressing or delaying nonessential telemetry transmissions. For the GSSC, it may be necessary to eliminate or defer certain aspects of training relating to insertion ship flight controllers. It was concluded that these changes can be made without seriously affecting the mission control function. If the present operating philosophy is not changed, there could be a large increase in the number of required computers.

During the study other configurations and modes of operation were considered, but lack of time precluded their detailed analysis. Hence, the major conclusions of the study are presented in two parts: augmentation requirements for the various schedules, assuming a stand-alone mode of operation; and, suggested areas for further study.

6.1 RTCC-GSSC Augmentation Requirements

There are three major factors which determine the number of computers needed in the RTCC: program development time per mission; reliability goals; and the number of simultaneous activities which must be supported.

There are presently five 360/75's in the RTCC, one in the SCATS area, and two 360/50's located off-line. These computers provide adequate support for schedule I, an Apollo-only schedule with two-month launch centers. They will also provide support for schedule V--an Apollo schedule with three-month launch centers interleaved with a "light" AAP schedule--subject to one restriction: if two critical phases occur simultaneously, it may be necessary to defer support of a third major activity* until completion of the critical support period. This condition, which arises from the limited number of computers with RTCC interfaces, is not deemed to be excessively restrictive in the case of schedule V.

If the number of missions per year were to increase as epitomized by schedule III, another computer would be desirable for RTCC program development and at times another GSSC would be needed for the support of simultaneous training exercises.

One way to accomplish this is to locate an additional computer in the SCATS area but give it sufficient interfaces so that it can be used for RTCC program development. In this

*For example: training, pad support, network testing.

manner, one more 360/75 will enable the MCC-H to support an Apollo schedule with two-month launch centers interleaved with a "light" AAP schedule subject to the same limitation stated previously. This limitation is not excessively restrictive for schedule III.

To remove the limitation, as would be desirable for supporting the first three years of schedules II and IV, it would be sufficient to replace the two off-line 360/50's with a 360/75 and put it in the RTCC. The sixth RTCC computer could be used for program development and, when needed, for mission support, thus providing the control center with the capability of supporting two critical phases and a major activity simultaneously. This approach would require some modification of facilities since the present RTCC computer room may not be able to accommodate six 360/75's.

Thus, eight 360/75's--six in the RTCC and two in the SCATS area--could handle the most demanding schedules analyzed in the study, with the possible exception of the fourth year of schedules II and IV. The number of computers required then cannot be fully determined since it depends on program development needs for the fifth year, a factor that was not estimated in the study.

6.2 Areas for Further Study

The stand-alone approach is in many ways inefficient. An entire computer is tied up in a mission, even during periods of low activity. There is no graceful way of handling overload conditions such as might be possible if a multiprocessing, load-sharing system were used. The large program sizes lead to increased overhead due to program swapping and more checkout time for the programs. CPU utilization during the real time program checkout is necessarily low since much of the time is spent waiting for input-output operations.

Several approaches to improving computer utilization deserve further study. It is possible to rearrange the processing tasks to support a mission so that one computer, or more if necessary, handles the telemetry data for all simultaneous missions while another computer processes trajectory data. The results of a MITRE study[2] indicate that there are potential advantages in this "functional" approach, particularly for heavy schedules. Future studies should investigate the functional approach in more detail from the standpoints of methods of implementation, CPU utilization, memory requirements, reliability (standby) criteria, and similar areas of concern.

In a multiprocessing environment, several processors are capable of operating in parallel, and the system assigns tasks to processors that are available. Implementing such a load-sharing operation involves both hardware and software of appreciable complexity. This concept appears to have particular advantages for handling jobs that require more processing speed than is possible with a single processor. The high CPU loadings of some AAP missions make this concept appealing for the RTCC.

Multiprogramming is a possible means of reducing the number of computers needed for program development. Some degree of multiprogramming has already been implemented: the 360/75's can carry on peripheral input-output activities as background, low-priority tasks while job-shop tasks are in process. It is possible to extend this concept to take advantage of CPU time available during real time checkout. The simplest approach would be to load and execute a non-real time job when a real time user's program is interrupted; his program would be reloaded and resumed immediately when he requested it. The fact that one program operates in real time and must have priority complicates the picture somewhat, but does not preclude this approach.

Other changes in hardware, software, or operating procedures may prove feasible in improving computer utilization. It is likely, for example, that many tasks now performed in block time could be accomplished in job-shop mode, which in general utilizes CPU time more efficiently.

Within the limitations of their manpower, IBM and MSC have been investigating many of these areas. More needs to be done in this regard to determine the practicability of various alternative approaches and choose the one with the best potential.

Another topic that warrants further study is the telemetry update cycle. As shown in this report, the update cycle time is an important factor in determining computer requirements, and expanding this time can lead to significant relaxation in computer loading. Although CCATS sends data to the RTCC once every second, many of the variables change value only once every ten seconds. Therefore, a considerable amount of redundancy exists in the telemetry data and its processing within the RTCC. It is conceivable to have the telemetry processing programs test for changes in the value of a variable and, if no change is detected, to bypass certain processing steps involving that variable. Operating in this manner would reduce the time spent in processing data, at the expense of some additional time consumed in testing the data to determine whether it should be processed further. Studies should be conducted to assess the potential benefits inherent in this approach. A decision could then be made as to whether these benefits are significant enough to justify the many software modifications necessary to realize them. Companion studies could be directed at the effects of a general increase in the telemetry update cycle time. The most obvious disadvantage of an increase cycle time is the potential loss of data; for example, if the cycle time were increased from one second to two seconds, it is possible that events of less than two seconds duration could begin and end between updates and pass unnoticed. The characteristics of telemetry data should be studied in detail to determine the likelihood of such short-duration events occurring and the effects on the mission if they are not observed. The results of this study could provide a basis for estimating a range of acceptable telemetry update cycle times and would be helpful in planning future growth of the capabilities of the MCC-H.

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Attachments
- References
- Appendix
- Tables
- Figures
- Acronyms

APPENDIX

An Analysis of RTCC Program Swapping Time

The amount of CPU time spent in program swapping is a function of the size of the program and the distribution of requests for the component subprograms. Swapping time in Apollo RTCC programs can be used as a guide for estimating swapping time in AAP computer programs. The program size for AS-504 is estimated to be greater than 5×10^6 bytes. Latest estimates indicate that swapping time for this program is 20% of a processing cycle. This figure will be used for other programs in the same size range. The following analysis will show that the AAP-3/4 programs fall into the range so that the 20% figure can be used in determining CPU loading.

The AAP-3/4 launch and rendezvous comprises maneuvers similar to those of the AS-258 mission. Hence, it will be assumed that the trajectory-oriented portion of the AAP-3/4 program will be comparable in size to that portion of the AS-258 program. IBM estimates for AS-258 program sizes are shown in Table A-1, which was taken from the August 23, 1967, RTCC Project Development Plan.[6] (Descriptions of each of the subprograms are given in the functional specification for the Earth Orbital Rendezvous Program.[7]) As can be seen from the Table, the trajectory processors, programs 1 through 5, for AS-258 require 1980×10^3 bytes of storage. This figure will be used in the AAP estimate.

It is also assumed that the residual programs and RTOS will be similar in size, i.e., 385×10^3 bytes.

The Mission Control program, which is used for sequencing subprograms, should be slightly bigger for AAP-3/4 since there are more mission phases to consider. We will assume a 20% increase, i.e., a total program size of 460×10^3 bytes.

The most significant increase will be in the size of the telemetry processing program. An approximation to the size of this program can be made by using AS-504 and AS-258 estimates and assuming that the size of a telemetry processor is proportional to its running time.

Appendix

From the data given in Table 1, it can be seen that the running times are 678 milliseconds* for the total set of telemetry processors in AS-504, and 1202 milliseconds** for the total set of telemetry processors in AAP-3/4. Therefore:

$$X = \frac{1202}{678} P_{504T} \qquad (1)$$

where P_{504T} is the size of the telemetry portion of the AS-504 program and X is the size of the telemetry portion of the AAP-3/4 program. P_{504T} is comprised of two parts: instructions and data. IBM has estimated the instruction size to be 200 x 10^3 bytes.(6) From Table A-1 we see that the ratio of tables to instructions for the AS-258 telemetry processor is 3.96. An examination of estimates for other programs indicates that the average ratio for the AS-501, 206, 258, and 502 telemetry processors is 3.5.(6) Using 4.0 to be conservative, P_{504T} becomes 1000 x 10^3 bytes.***

Substituting P_{504T} into equation (1) we find that the telemetry processor for AS-258 will require 1775 x 10^3 bytes of storage.

It is estimated that the digital command program size will be proportional to the number of vehicles commanded. We will assume that the increase in command programs will be similar to the increase in telemetry programs. Using the AS-258 estimates for digital command processing (which is larger than the one for AS-504) and multiplying by 1202/678 we get 151 x 10^3 bytes.

Adding all factors, as shown in Table A-2, we get $\sim$4800 x 10^3 bytes, which is less than the estimated size for AS-504. Hence, the swapping time for the AAP-3/4 program should be equal to or less than that for AS-504, which is estimated to be 20% of a processing cycle.

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*This number is obtained by adding the execution times for programs a thru i in Table 1.

**This number is obtained by adding the execution times for programs a and c thru k in Table 1, adding a and c in twice to account for the two launch vehicles.

***$P_{504T} = 200 \times 10^3 + 4(200) \times 10^3 = 1000 \times 10^3$.

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TABLE 1

RTCC PROGRAM EXECUTION TIMES

A. Telemetry Processing Time in Milliseconds (Including RTOS Overhead)

	Space Vehicle Program	Processing Time
a)	SIC or SI	46
b)	SII	49
c)	SIVB/IV	97
d)	CSM	171
e)	Aero Medical Data (AMD)	62
f)	Apollo Guidance Computer (AGC)	51
g)	Lunar Module (LM)	132
h)	LM Guidance Computer (LGC)	45
i)	LM Abort Guidance System (AGS)	25
j)	Orbital Workshop (OWS) Multiple Docking Adaptor (MDA) Airlock Module (AM)	260
k)	Apollo Telescope Mount (ATM)	170

B. Real Time Trajectory Processing

Phase	Trajectory Load Per Vehicle (percent of real time cycle)
Launch	14.49%
Major Burn	10.63%
Orbit	2.06%

C. Swapping Time

0-20% depending on size of total program.

TABLE 2

RTCC PROCESSING DURING CSM LAUNCH*

(Percent of a 1 Second Update Cycle)

Telemetry Processing

AAP-3		AAP-4		OWS-MDA-AM
CSM	17.1%	SIVB	9.7%	26%
AMD	6.2			
AGC	5.1			
SI	4.9			
SIVB	9.7			
Subtotals	43.0%		9.7%	26%

Total Telemetry Processing	78.7%
AAP-3 Trajectory Processing	14.5
AAP-4 Trajectory Processing	2.1
OWS-MDA-AM Trajectory Processing	2.1
	$\simeq$ 97%

*Including RTOS Overhead

TABLE 3

RTCC PROCESSING DURING CSM-LM/ATM
RENDEZVOUS WITH OWS-MDA-AM*
(One Second Telemetry Cycle)

Telemetry Processing

CSM	17.1%
AMD	6.2
AGC	5.1
LM	13.2
ATM	17.0
LGC	4.5
AGS	2.5
Subtotal	65.6%
OWS-MDA-AM	26.0
Total	91.6%

Total Telemetry Processing	91.6
CSM-LM-ATM Trajectory Processing	14.5
OWS-MDA-AM Trajectory Processing	2.1
Combined Processing	$\simeq$ 108%

*Including RTOS Overhead

TABLE 4

NON-UNIFORM PROGRAM DEVELOPMENT RATES

MONTHS BEFORE LAUNCH	PROGRAM DEVELOPMENT RATES (HRS/MO)			
	10,000 HR TOTAL	6000 HR TOTAL	3000 HR TOTAL	1500 HR TOTAL
12	225	135		
11	450	270		
10	625	375	7	3
9	675	405	23	12
8	750	450	30	15
7	1100	660	60	30
6	1225	735	60	30
5	1300	780	300	150
4	1600	1010	720	360
3	1300	780	900	450
2	600	360	600	300
1	75	45	300	150
MISSIONS ASSIGNED (See Figure 1)	A-1	C-1, F-1 H*, I	A-2, B-1, C-2, D-1, F-2, G-1, J, J', M	A-3 and ff., B-2 and ff., D-2, E-all, F-3, G-2, K, N

TABLE 5

NUMBER OF COMPUTERS REQUIRED
(RTCC ONLY, NON-UNIFORM DEVELOPMENT RATES)

CY	SCH	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC
1	I	4.4	4.1	4.6	6.4	7.2	4.7	5.6	5.6	5.0	5.7	5.4	4.4
	II	4.4	4.1	4.6	6.4	7.2	4.8	6.0	6.7	7.2	8.4	7.9	7.1
	III	4.4	4.1	4.6	6.4	7.2	4.7	5.7	5.6	5.1	5.9	5.6	5.1
	IV	4.4	4.1	4.6	6.4	7.2	5.1	6.3	6.9	7.2	8.4	7.8	6.4
	V	4.4	4.1	4.6	6.4	7.2	4.7	5.6	5.6	5.0	5.8	5.0	3.7
2	I	4.4	4.6	4.0	4.0	3.7	4.0	3.7	4.0	3.7	4.0	3.7	4.0
	II	6.6	6.2	6.0	5.6	5.3	5.7	5.8	5.8	5.3	5.6	5.5	6.0
	III	5.9	6.7	6.1	6.4	5.8	5.7	5.9	6.4	5.4	5.2	4.1	3.4
	IV	6.0	6.1	4.8	4.6	4.1	4.1	3.8	4.7	4.5	5.5	5.5	4.8
	V	4.4	5.5	5.4	6.3	6.3	4.4	5.0	5.5	4.7	4.8	5.3	4.3
3	I	3.6	3.9	3.6	3.9	3.3	3.1	2.4	2.2				
	II	4.9	5.7	5.4	5.2	3.8	4.0	3.8	4.6	5.6	7.0	6.6	7.0
	III	2.7	4.2	3.2	3.0	3.1	3.3	4.0	3.8	4.2	3.8	3.4	3.1
	IV	5.3	5.7	5.6	6.2	5.6	5.3	5.5	6.3	6.6	8.0	7.4	7.0
	V	5.2	5.6	4.9	4.1	3.9	3.3	4.0	3.8	4.2	3.8	3.4	3.1
4	I												
	II	7.4	5.4	5.1	5.3	5.6	6.1	6.9	6.4	5.0	4.6	3.6	3.4
	III	2.4	2.4	2.2	2.1	2.3	2.4	2.7	2.6	2.2	2.3	2.4	2.2
	IV	7.4	5.4	5.1	5.3	5.6	6.1	6.9	6.4	5.0	4.6	3.6	3.4
	V	2.4	2.4	2.2	2.1	2.3	2.4	2.7	2.6	2.2	2.3	2.4	2.2

Single underline - more than 5 computers required

Double underline - more than 6 computers required

Triple underline - more than 7 computers required

TABLE 6

NUMBER OF COMPUTERS REQUIRED
(RTCC ONLY, UNIFORM DEVELOPMENT RATES)

CY	SCH	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC
1	I	6.1	5.8	5.5	5.6	5.7	4.2	3.6	4.2	4.0	4.3	4.7	4.0
	II	6.1	5.8	5.5	5.6	7.2	6.2	5.6	5.2	6.0	6.3	6.5	5.7
	III	6.1	5.8	5.5	5.6	5.7	4.2	3.6	4.2	4.5	5.3	5.7	5.6
	IV	6.1	5.8	5.5	6.1	7.2	6.2	5.6	5.7	5.5	6.1	6.0	5.2
	V	6.1	5.8	5.5	5.6	5.7	4.2	3.6	3.7	3.5	5.1	5.2	4.4
2	I	4.1	4.3	3.6	4.0	3.6	4.0	3.6	4.0	3.6	4.0	3.6	4.0
	II	5.8	5.3	5.1	6.2	5.3	6.0	5.4	5.5	5.8	5.5	5.7	5.9
	III	6.3	6.8	6.0	6.3	5.8	5.3	4.7	5.0	4.1	3.8	3.3	3.5
	IV	5.2	4.7	4.5	5.0	4.9	5.0	4.3	4.7	4.1	4.8	5.8	5.3
	V	5.8	6.2	5.5	5.3	5.7	4.2	4.7	4.9	4.3	4.1	4.4	4.0
3	I	3.6	3.8	3.1	3.3	2.6	2.8	2.1	2.2				
	II	4.5	5.2	5.2	5.9	4.3	5.9	5.5	5.6	5.9	6.0	5.1	5.8
	III	2.6	3.4	2.3	2.8	3.5	3.6	4.2	4.6	3.6	4.3	2.6	2.9
	IV	6.1	5.4	5.8	6.8	6.2	7.1	6.7	6.8	5.6	6.8	5.9	5.8
	V	3.8	4.5	3.3	3.6	4.3	3.6	4.2	4.7	3.6	3.3	2.6	2.9
4	I												
	II	6.2	5.2	4.4	4.8	5.7	5.9	6.3	5.7	4.2	3.9	3.3	3.4
	III	2.5	2.6	2.4	2.1	2.3	2.5	2.6	2.4	1.8	2.0	2.1	2.2
	IV	6.2	5.2	4.4	4.8	5.7	5.9	6.3	5.7	4.2	3.9	3.3	3.4
	V	2.5	2.6	2.4	2.1	2.3	2.5	2.6	2.4	1.8	2.0	2.1	2.2

Single underline - more than 5 computers required

Double underline - more than 6 computers required

Triple underline - more than 7 computers required

TABLE 7

SUMMARY OF NUMBER OF COMPUTERS REQUIRED
(RTCC ONLY)

NON-UNIFORM DEVELOPMENT RATES

SCHEDULE	% OF TIME NEEDS EXCEED			PEAK REQUIREMENT
	5	6	7	
I	19	6	3	7.2 (May, CY1)
II	73	33	12	8.4 (Oct., CY1)
III	38	12	2	7.2 (May, CY1)
IV	69	40	15	8.4 (Oct., CY1)
V	27	8	2	7.2 (May, CY1)

UNIFORM DEVELOPMENT RATES

SCHEDULE	% OF TIME NEEDS EXCEED			PEAK REQUIREMENT
	5	6	7	
I	16	3	0	6.1 (Jan., CY1)
II	83	17	2	7.2 (May, CY1)
III	29	8	0	6.8 (Feb., CY2)
IV	69	29	4	7.2 (May, CY1)
V	25	4	0	6.2 (Feb., CY2)

TABLE 8

GSSC CPU LOADING ESTIMATES

PROGRAM	FUNCTION	CPU UTILIZATION INCLUDING RTOS OVERHEAD	PROGRAM SIZE (BYTES)
*SAT IB	Simulates the Uprated Saturn Launch Vehicle	7%	100,000
**SLV	Simulates the Saturn V Launch Vehicle	9%	125,000
*CSM	Simulates the CSM	9%	100,000
*LM	Simulates the LM	9%	150,000
**ATM	Simulates the ATM	5%	100,000
**OWS-MDA-AM	Simulates the OWS-MDA-AM	10%	100,000
*Ground Track	Simulates ground radars	7%	105,000
*ALTDS	Simulates the Apollo Launch Trajectory Data System (ALTDS)	4%	30,000
*Insertion Ship	Simulates trajectory processor on the insertion ship	30%	115,000
*SCA Interface	Interface with Simulation Controllers	19%	160,000
*TLM I/O	Formats telemetry stream from S/C	21%***	35,000
*FCT Interface	Interface with flight crew trainer	4%	30,000
RTOS and Subpool Storage	Data tables	---	382,000
		TOTAL	1,532,000

*Based on AS-504 estimates received from MSC.

**Extrapolation by the authors to AAP.

***Loading factor based on two vehicles; for each additional vehicle add 6%.

TABLE 9

CPU UTILIZATION FOR A CSM-SIB LAUNCH

PROGRAM	CPU UTILIZATION
SAT IB	7%
CSM	9%
Ground Track	7%
ALTDS	4%
Insertion Ship	30%
SCA Interface	19%
TLM I/O	21%
FCT Interface	4%
	101%

TABLE 10

AAP-3 LAUNCH

PROGRAM	CPU UTILIZATION	COMMENT
AAP-3 CSM	10%	Slightly more complex than AS-504 CSM
AAP-3 SATIB	7%	
AAP-4 LM	0%	Not transmitting during AAP-3 launch
AAP-4 ATM	0%	
AAP-4 SATIB	7%	
AAP-1/2 OWS-MDA-AM	10%	
SCA Interface	19%	
TLM I/O	33%	Four vehicles transmitting
FCT Interface	4%	
Ground Track	7%	
ALTDS	4%	
Insertion Ship	30%	
	131%	

131% x .85 = $\simeq$ 111%

TABLE 11

AAP-3/4 RENDEZVOUS WITH AAP-1/2

PROGRAM	CPU UTILIZATION	
AAP-3 CSM	10%	
AAP-4 LM	9%	Transmit telemetry as one vehicle
AAP-4 ATM	5%	
AAP-1/2 OWS-MDA-AM	10%	
SCA Interface	19%	
TLM I/O	27%	Three vehicles transmitting
FCT Interface	4%	
Ground Track	7%	
ALTDS	4%	
	95%	

$95\% \times .85 = \simeq 81\%$

TABLE 12

NUMBER OF COMPUTERS REQUIRED
(GSSC ONLY, NON-UNIFORM DEVELOPMENT RATES)

CY	SCHED.	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC
1	I	1.0	0.9	1.1	1.0	0.6	0.8	0.8	0.7	1.1	1.0	0.8	0.8
	II	1.0	0.9	1.1	1.0	0.6	0.9	1.0	1.2	1.6	1.6	1.4	1.4
	III	1.0	0.9	1.1	1.0	0.6	0.8	0.8	0.7	1.2	1.2	1.0	1.4
	IV	1.0	0.9	1.1	1.0	0.6	0.9	1.0	1.2	1.5	1.6	1.2	1.4
	V	1.0	0.9	1.1	1.0	0.6	0.8	0.8	0.6	1.1	1.0	0.7	1.0
2	I	1.3	0.8	1.3	0.8	1.3	0.8	1.3	0.8	1.3	0.8	1.3	0.8
	II	1.5	1.4	2.1	1.4	2.0	1.6	1.8	1.4	1.9	1.6	1.6	1.3
	III	1.8	1.4	1.9	1.6	1.6	1.4	1.9	1.4	1.6	1.0	1.1	0.6
	IV	1.3	1.0	1.3	1.3	1.2	1.0	1.3	1.3	1.4	1.6	1.1	1.4
	V	1.3	1.3	1.4	1.6	1.0	1.3	1.3	1.2	1.0	1.4	1.4	1.4
3	I	1.3	0.8	1.3	0.7	1.0	0.5	0.5	0.0				
	II	1.8	1.3	1.1	0.8	0.8	0.6	0.8	0.8	0.8	0.8	1.2	1.2
	III	1.0	0.5	0.6	0.6	0.8	0.3	0.8	0.8	1.1	0.8	0.7	0.5
	IV	1.6	1.4	1.4	1.6	1.4	1.4	1.6	1.3	1.3	1.3	1.2	1.2
	V	1.8	1.2	1.0	1.1	0.8	0.3	0.8	0.8	1.1	0.8	0.7	0.5
4	I												
	II	1.2	1.1	1.2	1.5	1.6	1.9	1.2	0.7	1.0	1.0	0.5	0.0
	III	0.6	0.6	0.3	0.2	0.6	0.6	0.8	0.2	0.5	0.5	0.5	0.0
	IV	1.2	1.1	1.2	1.5	1.6	1.9	1.2	0.7	1.0	1.0	0.5	0.0
	V	0.6	0.6	0.3	0.2	0.6	0.6	0.8	0.2	0.5	0.5	0.5	0.0

single underline - more than 1.0 computer required
double underline - more than 1.5 computers required
triple underline - more than 2.0 computers required

BELLCOMM, INC.

TABLE 13

NUMBER OF COMPUTERS REQUIRED
(GSSC ONLY, UNIFORM DEVELOPMENT RATES)

CY	SCHED.	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC
1	I	1.1	0.8	1.0	1.0	0.6	0.8	0.8	0.6	1.0	0.6	0.8	0.8
	II	1.1	0.8	1.0	1.0	0.6	1.0	1.0	1.2	1.6	1.2	1.4	1.4
	III	1.1	0.8	1.0	1.0	0.6	0.8	0.8	0.6	1.2	1.2	0.9	1.4
	IV	1.1	0.8	1.0	1.0	0.6	1.0	1.0	1.1	1.6	1.6	1.2	1.4
	V	1.1	0.8	1.0	1.0	0.6	0.8	0.8	0.6	1.1	1.2	0.6	1.1
2	I	1.3	0.8	1.3	0.8	1.3	0.8	1.3	0.8	1.3	0.8	1.3	0.8
	II	1.6	1.4	1.9	1.4	1.9	1.6	1.8	1.4	1.8	1.6	1.6	1.3
	III	1.8	1.4	1.8	1.6	1.6	1.4	1.8	1.4	1.5	1.1	1.1	0.6
	IV	1.3	1.0	1.4	1.4	1.2	1.1	1.4	1.1	1.4	1.6	1.1	1.4
	V	1.4	1.1	1.4	1.6	1.0	1.4	1.4	1.2	1.1	1.4	1.2	1.4
3	I	1.3	0.8	1.2	0.8	1.0	0.5	0.5	0.0				
	II	1.8	1.3	1.0	0.8	0.8	0.6	0.8	0.8	0.8	0.8	1.2	1.2
	III	1.0	0.6	0.6	0.6	0.8	0.3	0.8	0.8	1.0	0.8	0.8	0.6
	IV	1.6	1.4	1.4	1.6	1.4	1.4	1.6	1.3	1.4	1.4	1.2	1.2
	V	1.8	1.3	1.0	1.1	0.8	0.3	0.8	0.8	1.0	0.8	0.8	0.6
4	I												
	II	1.2	0.9	1.3	1.7	1.6	1.8	1.2	0.8	1.0	1.0	0.5	0.0
	III	0.6	0.6	0.2	0.3	0.6	0.6	0.8	0.2	0.5	0.5	0.5	0.0
	IV	1.2	0.9	1.3	1.7	1.6	1.8	1.2	0.8	1.0	1.0	0.5	0.0
	V	0.6	0.6	0.2	0.3	0.6	0.6	0.8	0.2	0.5	0.5	0.5	0.0

single underline - more than 1.0 computer required
double underline - more than 1.5 computers required

TABLE 14

SUMMARY OF NUMBER OF COMPUTERS REQUIRED
(GSSC ONLY)

NON-UNIFORM DEVELOPMENT RATES

SCHEDULE	% OF TIME NEEDS EXCEED			PEAK REQUIREMENT
	1.0	1.5	2.0	
I	31	0	0	1.3 (Jan., CY2)
II	62	25	2	2.1 (Mar., CY2)
III	31	12	0	1.9 (Mar., CY2)
IV	73	15	0	1.9 (June, CY4)
V	33	4	0	1.8 (Jan., CY3)

UNIFORM DEVELOPMENT RATES

SCHEDULE	% OF TIME NEEDS EXCEED			PEAK REQUIREMENT
	1.0	1.5	2.0	
I	28	0	0	1.3 (Jan., CY2)
II	58	27	0	1.9 (Mar., CY2)
III	31	10	0	1.8 (Jan., CY2)
IV	73	19	0	1.8 (June, CY4)
V	38	4	0	1.8 (Jan., CY3)

TABLE 15

NUMBER OF COMPUTERS REQUIRED
(RTCC AND GSSC, NON-UNIFORM DEVELOPMENT RATES)

CY	SCH	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC
1	I	5.4	5.0	5.7	7.4	7.8	5.5	6.4	6.3	6.1	6.7	6.2	5.2
	II	5.4	5.0	5.7	7.4	7.8	5.7	7.0	7.9	8.8	10.0	9.3	8.5
	III	5.4	5.0	5.7	7.4	7.8	5.5	6.5	6.3	6.3	7.1	6.6	6.5
	IV	5.4	5.0	5.7	7.4	7.8	6.0	7.3	8.1	8.7	10.0	9.0	7.8
	V	5.4	5.0	5.7	7.4	7.8	5.5	6.4	6.2	6.1	6.8	5.7	4.7
2	I	5.7	5.4	5.3	4.8	5.0	4.8	5.0	4.8	5.0	4.8	5.0	4.8
	II	8.1	7.6	8.1	7.0	7.3	7.3	7.6	7.2	7.2	7.2	7.1	7.3
	III	7.7	8.1	8.0	8.0	7.4	7.1	7.8	7.8	7.0	6.2	5.2	4.0
	IV	7.3	7.1	6.1	5.9	5.3	5.1	5.1	6.0	5.9	7.1	6.6	6.2
	V	5.7	6.8	6.8	7.9	7.3	5.7	6.3	6.7	5.7	6.2	6.7	5.7
3	I	4.9	4.7	4.9	4.6	4.3	3.6	2.9	2.2				
	II	6.7	7.0	6.5	6.0	4.6	4.6	4.6	5.4	6.4	7.8	7.8	8.2
	III	3.7	4.7	3.8	3.6	3.9	3.6	4.8	4.6	5.3	4.6	4.1	3.6
	IV	6.9	7.1	7.0	7.8	7.0	6.7	7.1	7.6	7.9	9.3	8.6	8.2
	V	7.0	6.8	5.9	5.2	4.7	3.6	4.8	4.6	5.3	4.6	4.1	3.6
4	I												
	II	8.6	6.5	6.3	6.8	7.2	8.0	8.1	7.1	6.0	5.6	4.1	3.4
	III	3.0	3.0	2.5	2.3	2.9	3.0	3.5	2.8	2.7	2.8	2.9	2.2
	IV	8.6	6.5	6.3	6.8	7.2	8.0	8.1	7.1	6.0	5.6	4.1	3.4
	V	3.0	3.0	2.5	2.3	2.9	3.0	3.5	2.8	2.7	2.8	2.9	2.2

Single underline - more than 6 computers
Double underline - more than 7 computers
Triple underline - more than 8 computers

TABLE 16

NUMBER OF COMPUTERS REQUIRED
(RTCC AND GSSC, UNIFORM DEVELOPMENT RATES)

CY	SCHED.	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC
1	I	7.2	6.6	6.5	6.6	6.3	5.0	4.4	4.8	5.0	4.9	5.5	4.8
	II	7.2	6.6	6.5	6.6	7.8	7.2	6.6	6.4	7.6	7.5	7.9	7.1
	III	7.2	6.6	6.5	6.6	6.3	5.0	4.4	4.8	5.7	6.5	6.6	7.0
	IV	7.2	6.6	6.5	7.1	7.8	7.2	6.6	6.8	7.1	7.7	7.2	6.6
	V	7.2	6.6	6.5	6.6	6.3	5.0	4.4	4.3	4.6	6.3	5.8	5.5
2	I	5.4	5.1	4.9	4.8	4.9	4.8	4.9	4.8	4.9	4.8	4.9	4.8
	II	7.4	6.7	7.0	7.6	7.2	7.6	7.2	6.9	7.6	7.1	7.3	7.2
	III	8.1	8.2	7.8	7.9	7.4	6.7	6.5	6.4	5.6	4.9	4.4	4.1
	IV	6.5	5.7	5.9	6.4	6.1	6.1	5.7	5.8	5.5	6.4	6.9	6.7
	V	7.2	7.3	6.9	6.9	6.7	5.6	6.1	6.1	5.4	5.5	5.6	5.4
3	I	4.9	4.6	4.3	4.1	3.6	3.3	2.6	2.2				
	II	6.3	6.5	6.2	6.7	5.1	6.5	6.3	6.4	6.7	6.8	6.3	7.0
	III	3.6	4.0	2.9	3.4	4.3	3.9	5.0	5.4	4.6	5.1	3.4	3.5
	IV	7.7	6.8	7.2	8.4	7.6	8.5	8.3	8.1	7.0	8.2	7.1	7.0
	V	5.6	5.8	4.3	4.7	5.1	3.9	5.0	5.5	4.6	4.1	3.4	3.5
4	I												
	II	7.4	6.1	5.7	6.5	7.3	7.7	7.5	6.5	5.2	4.9	3.8	3.4
	III	3.1	3.2	2.6	2.4	2.9	3.1	3.4	2.6	2.3	2.5	2.6	2.2
	IV	7.4	6.1	5.7	6.5	7.3	7.7	7.5	6.5	5.2	4.9	3.8	3.4
	V	3.1	3.2	2.6	2.4	2.9	3.1	3.4	2.6	2.3	2.5	2.6	2.2

single underline - more than 6 computers required
double underline - more than 7 computers required
triple underline - more than 8 computers required

TABLE 17

SUMMARY OF NUMBER OF COMPUTERS REQUIRED
(RTCC AND GSSC)

NON-UNIFORM DEVELOPMENT RATES

SCHEDULE	% OF TIME NEEDS EXCEED			PEAK REQUIREMENT
	6	7	8	
I	22	6	0	7.8 (May, CY1)
II	73	54	19	10.0 (Oct., CY1)
III	38	23	2	8.1 (Feb., CY2)
IV	71	50	19	10.0 (Oct., CY1)
V	33	8	0	7.9 (Apr., CY2)

UNIFORM DEVELOPMENT RATES

SCHEDULE	% OF TIME NEEDS EXCEED			PEAK REQUIREMENT
	6	7	8	
I	16	3	0	7.2 (Jan., CY1)
II	88	42	0	7.9 (Nov., CY1)
III	33	12	4	8.2 (Feb., CY2)
IV	79	42	10	8.5 (June, CY3)
V	23	6	0	7.3 (Feb., CY2)

TABLE A-1

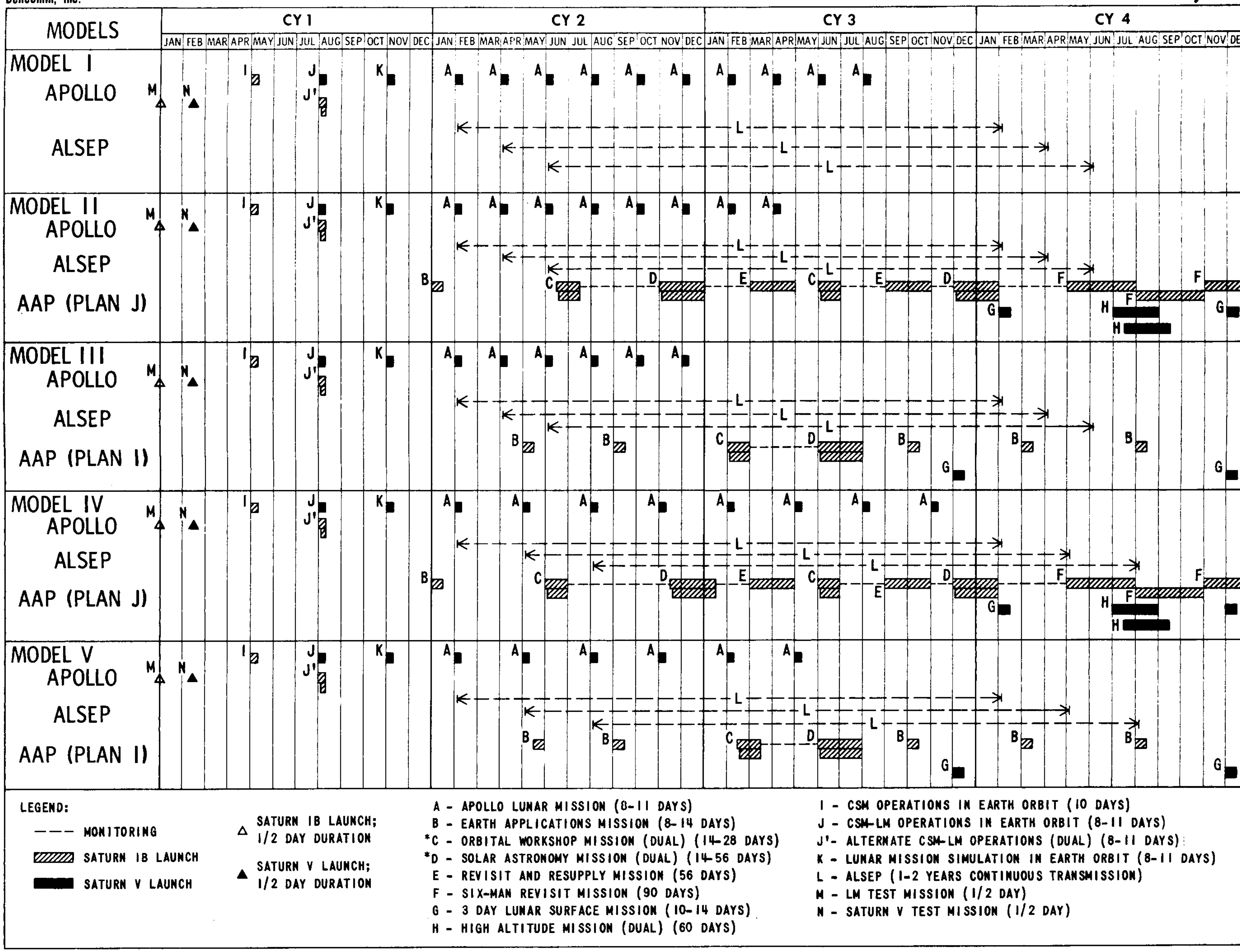
AS-258 PROGRAM SIZE ESTIMATES

	Instructions Storage Requirements (Thousands of Bytes)	Data Storage Requirements (Thousands of Bytes)	Total Storage Requirements (Thousands of Bytes)
(1) Launch Abort	182	31	213
(2) Mission Planning	414	94	508
(3) Orbit and Trajectory	305	39	344
(4) Reentry	346	56	402
(5) Trajectory Determination	383	130	513
(6) Mission Control	166	217	383
(7) Telemetry	172	680	852
(8) Digital Command	73	12	85
SUBTOTALS	2041	1259	3300
Residual Programs in Main Core			245
RTOS Programs in Large Core Storage			140
TOTAL PROGRAM SIZE			3685

TABLE A-2

AAP-3/4 PROGRAM SIZE ESTIMATES

PROGRAM	STORAGE REQUIREMENT (THOUSANDS OF BYTES)
Launch Abort	
Mission Planning	
Orbit and Trajectory	1980
Reentry	
Trajectory Determination	
Mission Control	460
Telemetry	1775
Digital Command	151
Residual and RTOS	385
TOTAL	4751



*MISSION C IS EQUIVALENT TO AAP-1/2
MISSION D IS EQUIVALENT TO AAP-3/4

FIGURE 1 - GOSS AUGMENTATION STUDY - MODEL SCHEDULES

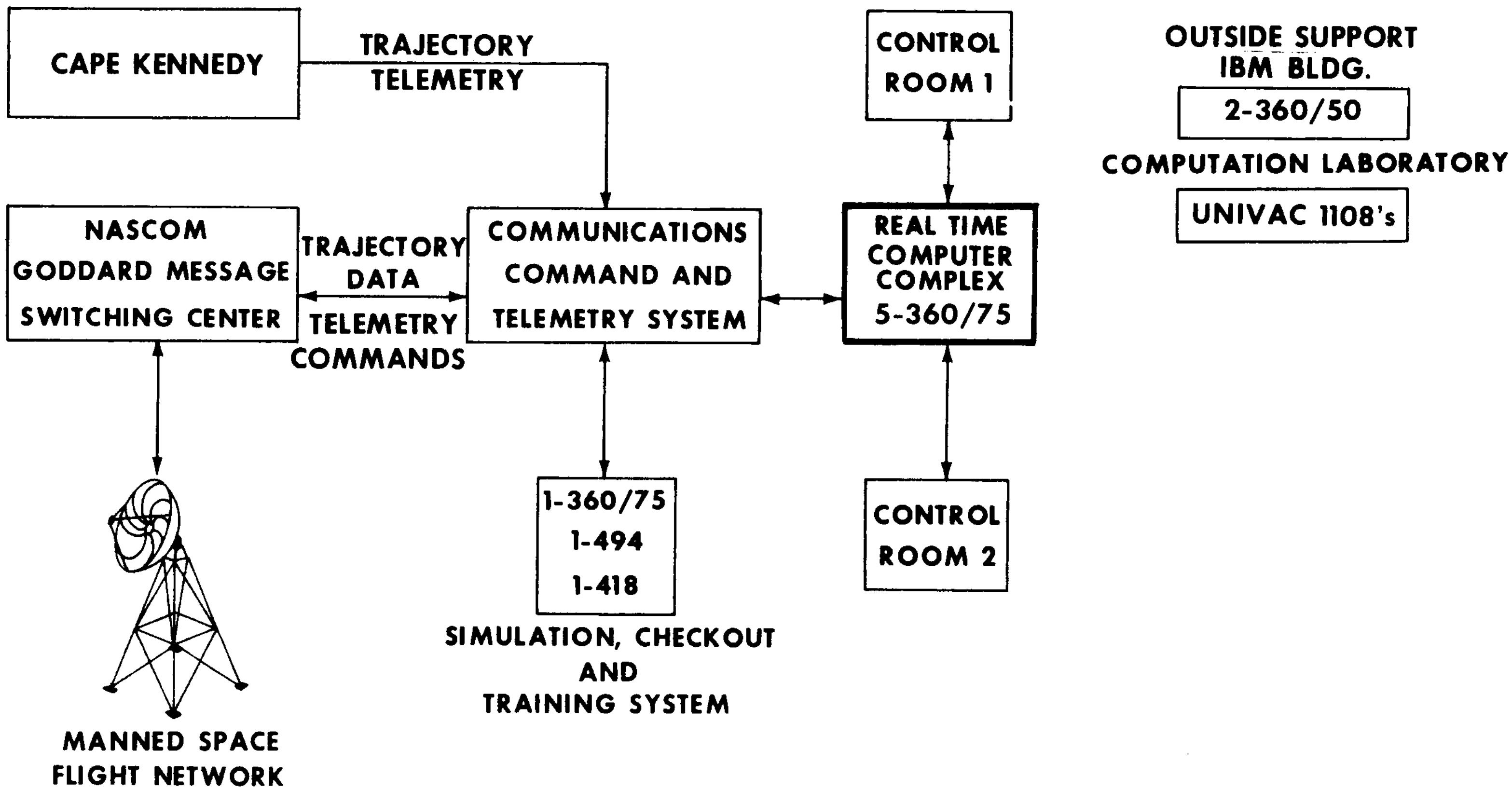


FIGURE 2 – MAJOR SYSTEMS IN THE GROUND NETWORK

ACRONYMS

AGC - Apollo Guidance Computer

AMD - Aeromedical Data

ATM - Apollo Telescope Mount

CCATS - Communications, Command and Telemetry System

CPU - Central Processing Unit

CSM - Command and Service Module

CSM-LM/ATM - Command Service Module-Lunar Module/Apollo Telescope Mount

DSC - Dynamic Standby Computer

GSSC - Ground Systems Simulation Computer

MCC-H - Mission Control Center-Houston

MOC - Mission Operational Computer

MSFN - Manned Space Flight Network

OWS-MDA-AM - Orbital Workshop Multiple Docking Adapter-Airlock Module

RTCC - Real Time Computer Complex

RTOS - Real Time Operating System

SCATS - Simulation, Checkout and Training System